Local HDTV Satellite Plan

January 19, 2004

Summary

This document describes a plan to deliver all local full-power broadcast television stations in all markets in1080i or 720p high definition (HD) format by satellite. Two high power Ka-band spot beam satellites are collocated on one orbital slot between 105 and 115˚ west *(in order to achieve a one-dish consumer-friendly solution)*. This satellite system forms a common platform that can deliver the local stations in HD to the customers of all US DBS operators.

Local stations furnish their 19.4 Mbps digital signal to regional uplink stations. Here the signals are re-encoded using a powerful compression algorithm, statistically multiplexed and transmitted to a Ka-band transponder. A dish receives the Ka-band signal and the DIRECTV and EchoStar transmissions. In the case of the VOOM service that originates from the 61.5° west orbital slot, a separate antenna is required. A set top box decodes the DIRECTV and Ka-band, or EchoStar and Ka-band, or VOOM and Ka-band, signals and delivers SDTV and HDTV outputs.

In addition to a powerful compression algorithm, the plan relies on 8-PSK modulation, advanced forward error correction techniques, and multiple spot beams. Conditional access rules are defined that allow the local HD signals to be transmitted once by the common platform satellites and yet received by customers of all the US DBS operators.

Putting in place a common platform requires that satellite operators cooperate. <u>If they choose not to, the spectrum saving techniques described in this Plan still can be used for the operators to separately offer all local stations in all markets in HDTV using a single Ka-band orbital slot each.</u>

Spectrum

The FCC has allocated 720 MHz in the Ka-band, split into two sub-bands as shown in Table 1. The bands are separated by 900 MHz. These frequencies and the restrictions on them are taken from the Report and Order FCC 00-212 that was adopted on June 8, 2000. Blanket licensing of terminals will be allowed in uplink and downlink frequencies of both bands. There is additional bandwidth available for uplink that might be used when the design is refined with a satellite manufacturer.

<u>Table 1 K_a-band Frequency Allocation</u>

Band	Uplink GHz	Downlink GHz	Translation GHz	Up Bandwidth MHz	Down Bandwidth MHz
I	28.38 – 28.60	18.58 – 18.80	9.8	220	220
II	29.50 – 30.00	19.70 – 20.20	9.8	500	500

Satellite Channels
The 720 MHz spectrum is divided into 46 channels making use of both left and right-handed polarization. Each channel is 26-27 MHz wide. This is a conventional subdivision used by DBS and some FSS satellites, where each 500 MHz provides 32 channels or 'frequencies' as they sometimes are called.

Each frequency will be re-used about eight times. This results in the equivalent of 370 transponders, which are divided between two satellites, i.e. each satellite supports about 185 equivalent transponders. The phrase 'equivalent transponders' is used to indicate that multiple carriers will be assigned to a single TWTA *(Traveling Wave Tube Amplifier)* and associated electronics in the satellite. Thus, while each carrier provides the equivalent capacity of a conventional transponder, it shares transponding hardware with other carriers.

The level of re-use planned here is not exceptional. DIRECTV-4S is configured to use six frequencies in 44 spot beams (7.33 re-use) and DIRECTV-7S will be configured to use four frequencies in 37 spot beams (9.25 re-use).

In addition to the 26-MHz wide television channels there will be two 10-MHz wide data channels with CONUS plus Alaska and Hawaii coverage. These channels carry system data from a central uplink to the regional broadcast centers (regional uplinks). This data delivery will be backed up by a terrestrial network.

Orbital Slot
An orbital slot in the 105 to 115˚ west range is required for the common platform one-dish solution. The purpose of this requirement is to allow reception from the Ka-band common platform as well as from any DIRECTV or EchoStar full-CONUS satellites by a single dish of standard design. The full-CONUS slots are at 101, 110 and 119° west.

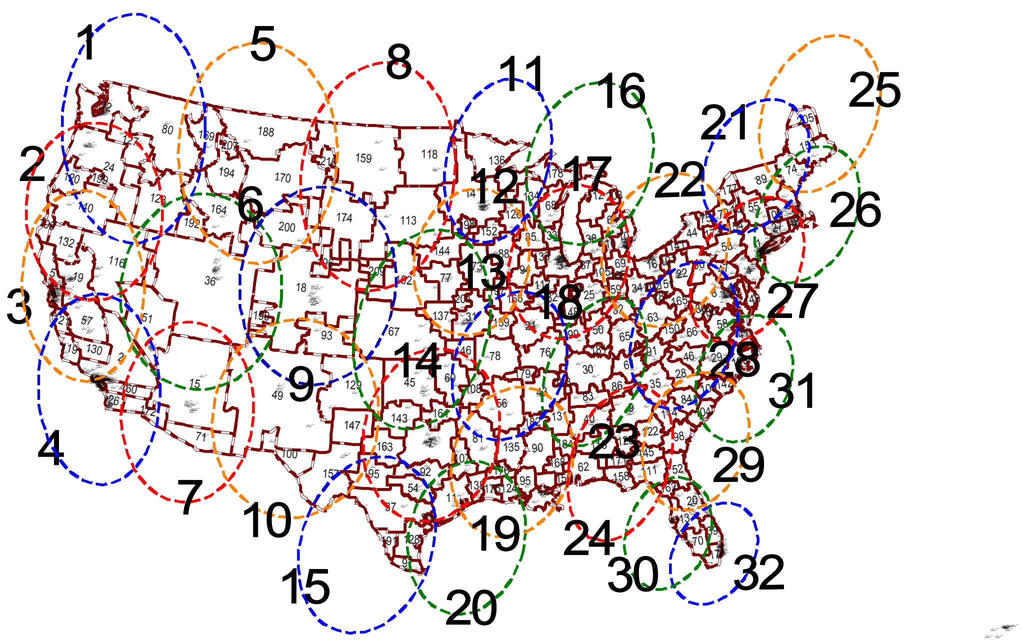
Reception of the common platform and VOOM requires either two conventional dishes or an aperture of non-conventional design.

Spot Beams

A large number of spot beams will be defined so that all 210 DMAs are covered. In all except a few fragmented DMAs, the entire DMA will fall within one spot beam. In the example shown the design goal was to cover all 210 DMAs and achieve 8x frequency re-use with the fewest spot beams. In addition, each beam is formed by one standard horn antenna. Alaska and Hawaii are covered but not shown.

Advantages of using as few beams as possible are:

- The beams are larger than when using many beams so that the horns are smaller and are easier to fit onto the space platforms
- Larger beams lead to a less stringent attitude control requirement for the satellites
- Keeping the number of beams small (and thus fewer horns) allows all the beams to be provided from one satellite. All markets are therefore covered by one satellite. A market obtains about half its capacity from each of the satellites. In the event of a satellite failure all markets can still be served, albeit at lower bit rate, while a replacement satellite is prepared. This self-sparing avoids the expense of building a spare satellite at the outset of the program.



In the spot beam example above the color of a spot beam indicates its frequency plan i.e. the subset of the total of 46 frequencies assigned to that spot beam.

The arrangement of spot beams and frequency plans will be refined during the satellite design phase with the satellite manufacturer. One of the design goals is to ensure that inter-beam interference is minimized so that the worst case total C/I (carrier to interference ratio) experienced by a user within any 5-dB spot beam contour with a standard receive system and with both satellites operating normally will be 11-dB. The 5- dB contour is the spot beam defined by power levels 5-dB down from peak power in the spot.

In most cases the ratio will be significantly above the 11-dB level. Design studies and experience with spot beams satellites have shown that this goal is achievable and that it results in reception availabilities in line with industry norms. In addition, the noise power ratio (NPR) within the operating bandwidth of any spot beam transponder, with the linearized TWTA nominally operating at 3 dB output back-off, will be at least 16 dB.

The consumer receiver will have an availability of 99.7% *(conservative)* measured on a contour 3-dB down from beam peak power. The beam contours will be such that no part of a DMA receives a signal more than 5-dB down from the peak power in the beam.

Signal delivery to uplinks

Stations deliver their signals at 19.4 Mbps to one of the local uplinks maintained by the system. At the uplink the station signal will be re-encoded using a highly efficient compression algorithm. Two algorithms are under consideration - they are the MPEG4 part 10 (AVC or H.264) algorithm and the Windows Media 9 (WM9) algorithm. If a local station delivers its primary signal in 720p or 1080i format, that signal will be re-encoded in the same format using AVC or WM9.

An average of five re-encoded signals will be statistically multiplexed and uplinked to a transponder.

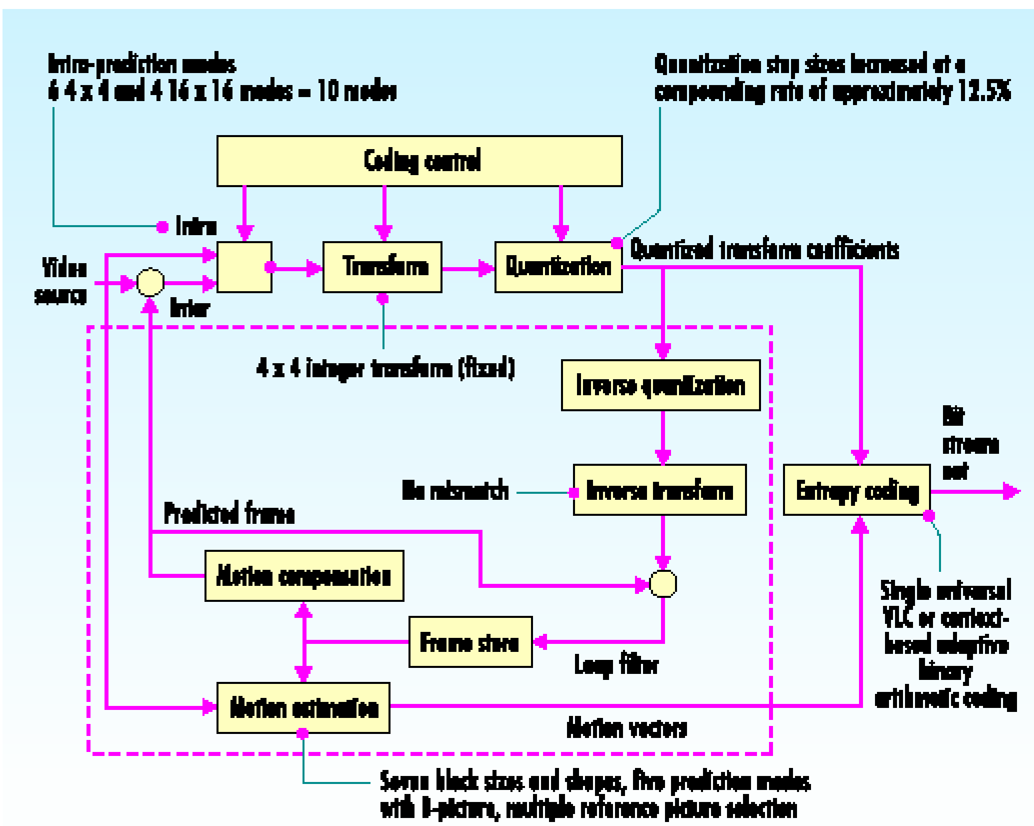
Source Coding

The following discussion of compression techniques (see Markandey et al) is intended to highlight the improvements incorporated in AVC compared with MPEG-2, which is currently used for satellite and terrestrial HDTV. It is now seven years since WRAL in Raleigh, N. Carolina became the first commercial DTV station to broadcast a digital signal. There has been a steady improvement in the performance of MPEG-2 over that time and there are claims that 12-14 Mbps MPEG-2 now yields the same quality that 19 Mbps did in the original broadcasts seven years ago. But in spite of this steady improvement; significant advances in processing power, the lower cost of memory, and the better understanding of compression techniques, have led to a new generation of algorithms. These algorithms provide a jump in the efficiency of the compression process. It is now widely believed, and our experiments confirm, that HDTV of similar quality to that delivered by MPEG-2 at 19 Mbps can be delivered by AVC or WM9 at 6-9 Mbps.

Video Compression
Main Profile AVC, developed for broadcast applications, uses its own video tools such as B pictures in several prediction modes, weighted prediction, and adaptive frame and field coding. While some of the broadcast application-specific tools are variations of tools used in MPEG-2 or MPEG-4 ASP, the Main Profile's context-adaptive binary arithmetic coding (CABAC) scheme is new.

AVC Processing Stages
AVC consists of the following processing stages:

1. Motion (Inter) Estimation
2. Spatial (Intra) Prediction
3. Transform
4. Quantization
5. Loop Filter
6. Entropy Coding



Video is composed of a stream of individual pictures that can be broken down into individual blocks of 16 pixels by 16 lines called "macroblocks". This practice simplifies the processing which needs to be done at each stage in the compression algorithm. For example, a picture from a video stream at standard definition resolution (720x480) is divided into 1,350 (45x30) macroblocks. It is at the macroblock level that further processing takes place.

Motion Estimation
Motion estimation is used to identify and eliminate the temporal redundancies that exist between successive frames. When searching for motion relative to a previous picture, the picture to be encoded is called a "P-picture". When searching both within a previous picture and a future picture, the picture to be encoded is called a "B-picture".

To improve coding efficiency, in AVC the macroblock is broken down into smaller blocks that attempt to contain and isolate the motion. Then, motion vectors to previous and/or future pictures are used to predict a given block. Thus, AVC introduces smaller block sizes than MPEG-2, greater flexibility in block shapes, and greater precision in motion vectors. By defining various blocks within a macroblock up to 16 motion vectors may be transmitted for a macroblock, compared with one for MPEG-2. There are multiple block modes, ranging from the entire macroblock to the division of the macroblock into sixteen 4x4 blocks (hence 16 motion vectors per macroblock). The intermediate modes divide the macroblock into 2, 4 and 8 blocks in various ways.

	Block Shape	Smallest inter block	Motion resolution
MPEG-2	Square	16x16	½ pixel
MPEG-4 ASP	Square	8x8	¼ pixel
MPEG-4 AVC	Arbitrary	4x4	¼ and 1/8 pixel

In addition, AVC introduces the concept of multiple reference frames. This feature is useful for dealing with:

1. Motion that is periodic in nature
2. Translating motion and occlusions
3. Alternating camera angles that switch back and forth between two different scenes

For example, a motion sequence of a bird flying shows periodic motion of the wings. Images with the wings at different positions can be chosen as reference frames, recognizing the periodic motion of similar images and leading to increased compression. Thus, each block within the macroblock may predict from a different reference frame. Up to five different reference frames can be selected.

It is the difference between a predicted block and the actual block that is coded, resulting in far fewer bits than if only the original block was coded. In AVC there are many possibilities for the predicted block. To find the block producing the minimum mismatch with the reference, a sum-of-absolute-differences (SAD) is computed at a number of locations within the search window. An exhaustive search that evaluates the SAD at every pixel location in the search area can be used, although there are algorithms to restrict the search to fewer points.

Spatial (Intra) Prediction
In instances where motion estimation cannot be exploited, intra estimation is used to eliminate spatial redundancies within a frame. The resulting frame is called an "I-picture". Intra estimation attempts to predict the current block by extrapolating the neighboring pixels from adjacent blocks in a defined set of different directions. The difference between the predicted block and the actual block is then coded. This approach, unique to AVC, is particularly useful in flat backgrounds where spatial redundancies often exist.

MPEG-4 ASP allows intra prediction in the frequency domain, whereas AVC performs it at the pixel level. AVC allows many prediction modes because different block sizes can be used and different neighboring pixels can be used in a variety of directions to obtain predicted values for a block. AVC offers multiple modes of prediction using 4x4 luminance blocks and, for regions of the picture with less detail, four additional modes using the whole 16x16 macroblock. MPEG-2 uses only 8x8 pixel blocks for spatial compression.

Transform (and Inverse Transform)
Results from the motion estimation or intra estimation stages are transformed from the spatial domain into the frequency domain. AVC uses a DCT-like 4x4 integer transform. In contrast, MPEG-2 and MPEG-4 ASP employ a true DCT 8x8 transform that operates on floating-point coefficients.

The smaller block size of AVC reduces blocking and ringing artifacts. Integer coefficients eliminate rounding errors that cause-drifting artifacts with MPEG-2 and MPEG-4 ASP and that are inherent to floating point coefficients.

Quantization (and Inverse Quantization)

The coefficients from the transform stage are quantized, which reduces the overall precision of the integer coefficients and tends to eliminate high frequency coefficients, while maintaining perceptual quality. The quantizer is also used for constant bit rate applications where quantization is varied to control the output bit rate.

Thirty-two different quantization steps can be chosen on a macroblock basis. In AVC the step size is increased at a compounding rate of about 12.5% rather than by a constant increment as in earlier standards.

In AVC a smaller step size is used to quantize chroma than luminance samples to improve chroma fidelity.

Loop Filter

The AVC standard defines a de-blocking filter that operates on both 16x16 macroblocks and 4x4 block boundaries. In the case of macroblocks, the filter is intended to remove artifacts that may result from adjacent macroblocks having different estimation types (e.g. motion vs. intra estimation), and/or different quantizer scales. In the case of blocks, the filter is intended to remove artifacts that may be caused by transform/quantization and from motion vector differences between adjacent blocks. The loop filter typically modifies the two pixels on either side of the macroblock/block boundary using a content adaptive non-linear filter.

In AVC the filter to remove blocking and ringing artifacts is moved into the coding loop so that temporal prediction is based on decoded images.

Entropy Coding

Before entropy coding can take place, the 4x4 quantized coefficients must be serialized. Depending on whether these coefficients were originally motion estimated or intra estimated, a different scan pattern is selected to create the serialized stream. The scan pattern orders the coefficients from low frequency to high frequency. Then, since higher frequency quantized coefficients tend to be zero, run-length encoding is used to group trailing zeros, resulting in more efficient entropy coding.

The entropy coding stage maps symbols representing motion vectors, quantized coefficients, and macroblock headers into actual bits. Entropy coding improves coding efficiency by assigning a smaller number of bits to frequently used symbols and a greater number of bits to less frequently used symbols.

MPEG2 uses Variable Length Coding (VLC), while the main profile of AVC uses Context Adaptive Binary Arithmetic Coding (CABAC). CABAC offers superior coding efficiency over VLC by adapting to the changing probability distribution of symbols, by exploiting correlation between symbols, and by adaptively exploiting bit correlations using arithmetic coding. AVC also supports Context Adaptive Variable Length Coding (CAVLC) which offers superior entropy coding over VLC without the full cost of CABAC.

Coding Control

Improvements in video compression can be achieved by allowing the encoder to make a larger number of choices in the coding process. Many more coding modes are possible with AVC than with previous standards. As the number of choices increases, the search and rate-distortion optimization tools used in the encoder become increasingly important.

Audio Compression

MPEG-1 Layer 2 audio is widely used in DBS systems. It delivers high quality stereo at 128 Kbps. MPEG-4 Advanced Audio Coding (AAC) is a powerful codec that offers the same quality at 64 Kbps. MPEG-4 audio is capable of coding 5.1-channel surround sound.

MPEG-4 AAC has been extended with a technique called Spectral Bandwidth Replication (SBR). The SBR extension allows the delivery of high quality stereo audio at 48 Kbps. XM Radio uses AAC-SBR.

The plan for this project is to take the Dolby AC-3 5.1 channel audio that is part of the terrestrial HDTV signal and re-encode it using AAC, retaining the 5.1 channel structure. The bit rate will drop from the terrestrial value of 384 Kbps to about 200 Kbps without sacrificing quality.

Channel Coding

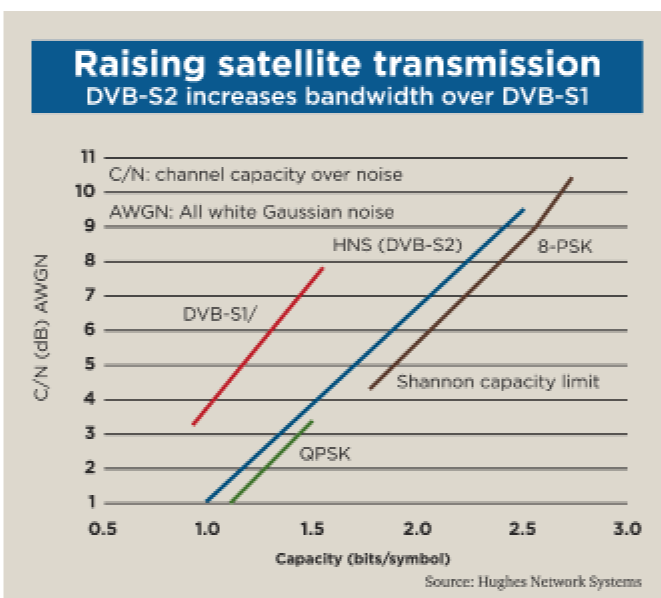
Satellite operators make extensive use of QPSK modulation and concatenated convolutional-Reed Solomon forward error correction. This combination is incorporated in the DVB-S standard. But recently developed coding schemes based on iterative coding and higher order modulation offer much improved performance. The main advances in signal transmission have been new chips which offer 8-PSK modulation and turbo forward error correction coding. Using 8-PSK modulation allows a higher throughput in a satellite transponder (allowing more channels), but at the expense of requiring higher satellite power and/or larger receive antenna size. The new Turbo codes, however, give error correction efficiencies significantly better than previous technologies allowing some of the losses of using 8-PSK to be overcome.

Turbo coding and 8-PSK modulation is already in use on a small scale, with chip sets available from a few manufacturers. EchoStar seems to be incorporating the chips into every new HD STB and plans to use this transmission scheme for the 110-degree signals. DIRECTV has not made public its 8-PSK intentions.

The DVB has updated its satellite standard to DVB-S2 after a technical evaluation of a number of proposals that included Turbo codes. However, the DVB chose a code called Low Density Parity Check (LDPC) to pair with 8-PSK and other modulation schemes. The best proposals evaluated by the DVB are within 1 dB of the Shannon capacity which defines the ultimate level of performance for a communication channel.

The performance of Turbo code and LDPC code coupled with 8-PSK are similar. The Turbo solution is more compute-intensive while LDPC requires more memory. Apparently the ease of implementation swayed DVB in favor of LDPC. The technique was developed by Robert Gallager in the 1960s but languished because of its relatively large memory requirement.

When the first DVB-S2 call for proposals went out on FEC and modulation, Hughes was the only company to propose LDPC (see Yoshida). The other proposals, submitted by companies including Philips, STMicroelectronics and Conexant, concentrated on three basic approaches: turbo codes, serial turbo codes and turbo product codes. Hughes, which had already designed its own LDPC implementation, is now positioning itself as the first supplier of licensable cores to chip vendors under pressure to master LDPC technology fast.



Because LDPC itself was invented so long ago, intellectual-property rights covering its theory or concept are no longer an issue, Lee said.

However, Hughes owns IP related to its specific LDPC implementation, which the company has promised, through its proposal to the DVB group, to offer to others in a fair, reasonable and nondiscriminatory manner.

At the same time, the company has turned its attention to cores and is now offering three of them: the basic LDPC code core for forward error correction; a combo core tying the LDPC solution with a BCH core in an LDPC-BCH decoder; and a separate demodulation core designed to enhance existing modulation technology, such as 8PSK, by applying some specific digital signal processing. They can be licensed either separately or as one package. BCH, a simple error-correcting code, is used as a clean-up code and it is a necessary component of the LDPC-code-based FEC.

Other companies are beginning to describe DVB-S2-compliant devices based on the final draft standard.

Given the relationship between DIRECTV and HNS it is possible that DIRECTV will adopt the HNS DBV-S2 LDPC solution when it implements 8-PSK modulation.

Turbo Code /8-PSK hardware is available now and LDPC Code/8-PSK hardware that is DVB compliant should be available in 2004. Thus, both technologies will be available in the time frame needed to implement this Plan. They offer much better performance than current practices and the use of either or both in this Plan depends on the choices made by the satellite operators.

HDTV Channels

Each equivalent transponder will carry four to six multiplexed television signals, the average capacity being five channels. With about 370 equivalent transponders available, the system capacity will exceed 1800 HDTV channels - this is sufficient capacity to carry all of the approximately 1600 local TV stations in HD.

Bit Rates

Our system will use 8-PSK modulation with a symbol rate of 20.5 Msps. In transponders that are 26-27 MHz wide, the roll-off is about 0.3, which is within the 0.2 to 0.35 range already being offered by manufacturers adhering to DVB-S2 specification. Using a rate 2/3 Turbo Code or LDPC code forward error correction, 41 Mbps of useful payload will be available in each equivalent transponder. The five TV signals in each transponder are allocated an average of 7 Mbps for video and 200 Kbps for audio. This takes up 36 of the available 41 Mbps, leaving 5 Mbps for system data, mainly conditional access and program guide information.

Note that 7 Mbps is the average bit rate allocated to a video stream. The use of statistical multiplexing allows an individual video rate to exceed 7 Mbps when needed, for instance, when a difficult scene is encountered.

Total Satellite Throughput

The throughput of each satellite is 11.4 Gbps (185 equivalent transponders at a total bit rate of 61.5 Mbps each). This is at the upper end of the range of currently available commercial spacecraft, i.e. the system requires two large satellites to be collocated at one orbital slot.

Receive dish and Set Top Box

A 28 x 23-inch Ka-band dish is required. It will be equipped with feed horns to receive the DBS signals and the Ka-band signals from the system's orbital location. For DIRECTV there will be feedhorns receiving from 101°, 110°, 119° and Ka-band, for EchoStar feedhorns will receive from 110°, 119° and Ka-band, and for VOOM separate dishes will receive from 61.5° and Ka-band.

In a study with a manufacturer of outdoor units for the DBS industry it was established that the 28x23-inch dish was more than adequate to receive from the multiple locations listed above, and to protect against 2° Ka-band satellite spacing and worst case C/I of 11 dB while providing conventional availabilities in the worst rain region. The calculations were based on the use of 8-PSK modulation and took advantage of the performance gain from Turbo or LDPC codes to close the link.

The use of these new technologies requires that DBS subscribers wishing to access these local HDTV channels obtain a new set top box in addition to a new dish. Like the dish, the set top box will be individual to the different DBS operators so that current programming also can be received. It is probable that the new technology with new dishes and set top boxes will be required in any case if DBS is to continue to compete against cable TV in the national channel arena.

A Common Platform

Microspace Communications Corporation, a Capitol Broadcasting Company, Inc.company, filed for a common platform for DBS systems (U.S. Patent Application No. 10/446,543, Filed May 28, 2003 *Systems, Methods and*

Transmission Formats for Providing a Common Platform for Direct Broadcast Satellite Television Networks). The common platform allows local or other TV signals to be transmitted to a single satellite system and be received by all US DBS subscribers. The invention is summarized below.

A multi-beam Direct Broadcast Satellite (DBS) system with ground processing components capable of delivering programming in an efficient manner to subscribers of DIRECTV, EchoStar and VOOM networks is disclosed. The inventive system achieves its efficiency by delivering the satellite signals in such a way that subscribers to distinct DBS networks are able to receive the same signals. The invention is intended to allow subscribers of the DIRECTV, EchoStar, and VOOM networks to receive the same signal but reception is not limited to these networks. Future DBS network subscribers also will be able to receive the signal. The combination of satellite and ground processing equipment provides a common platform for DBS networks.

The common platform satellite system can be located in the vicinity of the satellites operated by DIRECTV and EchoStar, so that subscribers can receive signals from the common platform system and from one of the DBS systems, using the same dish.

DBS systems are incompatible, so that a DIRECTV customer cannot receive EchoStar services and an EchoStar customer cannot receive DIRECTV services. The DBS systems therefore duplicate programming at considerable capital, operating and spectrum inefficiency.

This invention ameliorates the situation by allowing a single satellite broadcast of material to be received by DIRECTV, EchoStar, and VOOM subscribers who can continue to receive programming from DIRECTV if they are DIRECTV subscribers or from EchoStar if they are EchoStar subscribers or from VOOM if they are VOOM subscribers.

In order to provide a platform that is compatible with DIRECTV, EchoStar, and VOOM, the distinguishing features of these systems are considered. The design features of the inventive system are:

- Modulation parameters
- Signal Transport format
- Conditional Access and encryption/decryption technology
- Electronic Program Guide
- Video and Audio Decoding
- Outdoor Satellite Antenna and Feed
- Data Capabilities

Each of these features is supported in set-top boxes (STBs) in a manner that accommodates services from the common platform system and one of the DBS systems. Thus, there are DIRECTV/common platform compatible set-top boxes and EchoStar/common platform compatible set-top boxes, and VOOM/common platform compatible set-top boxes. In this way a common platform for local TV and audio and data services is established.

Current technology provides the means to cost effectively deploy a common platform for television, audio and data services. Software enhancements, multi-function chipsets, and an extra feed on the consumer antenna are the main contributions made to realize a common platform for DBS providers. While Digital Video Broadcasting (DVB)-compatible components and technologies are identified in the description of the invention, such compatibility is not essential to create a common platform. Other technologies can be substituted to achieve the same result.

Modulation Parameters

The common platform could use standards-based modulation schemes (DVB) that are supported in the chipsets used in the DBS/common platform set-top boxes, but the use of non-standard modulation technology is not precluded.

Signal Transport Format

The common platform could use the transport streams that are consistent with the Advanced Television Systems Committee (ATSC) and DVB standards but this is not essential to the invention.

Conditional Access and Encryption Technology

The common platform allows EchoStar, DIRECTV, and VOOM providers to authorize the common platform services. The common platform will employ extensions to proven DVB simulcrypt technology to allow multiple Conditional Access Systems to control access to the same services.

Electronic Program Guide

The common platform will carry channel information that can identify common platform channels and programming to the STB and that can be associated with the DBS EPG data streams (which may or may not carry programming information for common platform channels).

Video and Audio Decoding

The common platform STBs will contain chipsets that can decode both the common platform and the DBS video and audio streams. There is no restriction on the common platform video and audio formats – they can be identical to one of the DBS formats or different from them.

Antenna
The DBS/common platform antenna may consist of a single reflector with multiple feed horns or of individual reflectors for the DBS and common platform satellites. Array antennas may also be employed.

Data Services
The common platform adds data capacity in each market that is accessible by the common platform component in each STB, PC receiver card or other data-centric receive system designed to operate with the common platform.

Common Platform Advantages
The invention provides the following advantages over current methods:

1. It conserves DBS spectrum by allowing a single transmission of programming rather than the current multiple transmissions
2. It saves space segment (launch vehicle, spacecraft, operations) costs by avoiding duplication of satellite transmissions
3. It saves ground segment costs (signal backhaul to DBS uplink sites, uplink equipments and operations)
4. It provides a uniform platform for data delivery and interactive television services.

Material Degradation
FCC Position
The FCC has written 'We specifically note that degradation may result when the satellite carrier encodes an analog broadcast signal and readies it for digital retransmission. During the encoding process, certain artifacts may be introduced into the original material that would have an effect on picture quality. The most dominant artifact is quantization noise in the picture. This effect is often visible on edges of subjects and textured areas of the image. It is caused when there is a high amount of picture detail along with a high degree of picture activity and levels of quantization are restricted due to data rate reduction. Random noise can also be introduced into the source video. This can result in activity or "busyness" in detail areas of the picture and tiling or flicker in other areas of the picture. Such effects are caused by the encoder attempting to encode random noise. During the encoding process of rapidly moving images, certain data reduction techniques can result in another artifact known as "dirty window," where noise appears stationary while images behind it are moving.

To satisfy the material degradation principles in the Act, we will adopt a simple comparability rule. That is, a satellite carrier should treat all local television stations in the same manner with regard to picture quality. The signal processing, compression and encoding techniques a satellite carrier uses to carry retransmission consent stations should also be used for mandatory carriage stations. This rule comports with the non-discriminatory thrust of Section 338 and the SHVIA. As long as all local television stations are treated equally, and the degradation resulting from processing these stations does not exceed the level for the lowest quality non-broadcast video service provided by the carrier, we will refrain from prohibiting compression methods. We recognize that compression technology is rapidly evolving and we do not want to impede innovation by proscribing certain techniques. We also believe that new compression methods may benefit subscribers as satellite carriers could offer more services, particularly those involving broadband applications.

We decline to adopt, as a rule, any one specific technique for measuring degradation. After some experience with satellite broadcast signal carriage, broadcasters and satellite carriers will be able to apply such a technique for analog-to-digital degradation measurements. At some future point, the Commission will be in a better position to scrutinize the techniques used and establish standards, if necessary.'

Objective Video Quality Evaluation
Simple objective criteria can be computed from the root mean square error between a mxn original image Y(m,n) and the impaired image Y′(m.n). The RMS error can be used to compute a signal-to-noise-ratio (SNR) as well as a peak SNR or PSNR. However, the distortion calculated by an objective quality metric like PSNR might not match the subjective perception of a human being as it does not take into account:

- Motion
- Sensitivity of the eye to contrast and spatial/temporal details
- Blocking

But, after examining more sophisticated objective evaluation models, the Video Quality Experts Group (VQEG) of the ITU reported in 2000:

- No perceptual model is able to fully replace subjective testing.
- No perceptual model statistically outperforms the others in all reference conditions.
- No perceptual model statistically outperforms PSNR in all reference conditions.
- Based on present evidence, no single method can be recommended to ITU at this time.

The IEEE G-2.1.6 Compression and Processing Subcommittee continues to work to define an objective standard.

Comparison of H.264/AVC coding efficiency with prior coding standards
Schäfer et al used PSNR to evaluate AVC. For demonstrating the coding performance of AVC, they compared it with MPEG-2 Visual, H.263++, and MPEG-4 Visual for a set of QCIF (10 Hz and 15 Hz) and CIF (15 Hz and 30

Hz) sequences with different motion and spatial detail. The QCIF sequences were: *Foreman*, *News*, *Container Ship* and *Tempete*. The CIF sequences were: *Bus*, *Flower Garden*, *Mobile and Calendar* and *Tempete*. All video encoders were optimized for rate-distortion efficiency using Lagrangian techniques.

During these tests, the MPEG-2 Visual encoder generated bit streams at the well-known MP@ML conformance point, and the H.263++ encoder used the features of the High Latency Profile (HLP).

In the case of MPEG-4 Visual, the Advanced Simple Profile (ASP) was used with quarter-sample-accurate motion compensation and global motion compensation enabled. Additionally, the recommended deblocking/ deringing filter was applied as a post-processing operation.

For the H.264/AVC JM-2.0 coder, the features enabled in the Main profile were used. They used five reference frames for both H.263 and H.264/AVC, with the exception of the News sequences where they used more reference frames for exploiting the known redundancies within this special sequence. With all the coders under test, only the first picture of each sequence was coded as an I-picture, and two B-pictures were inserted between two successive P-pictures. For H.264/AVC, the B-pictures were not stored in the multi-picture buffer, and thus the following pictures did not reference them. Full search motion estimation, with a range of 32 integer pixels, was used by all the encoders along with the Lagrangian coder control. The bit-rates were adjusted by using a fixed quantization parameter.

The average bit-rate savings provided by each encoder, relative to all other tested encoders over the entire set of sequences and bit-rates, are depicted in *Table 1*. It can be seen that AVC significantly outperforms all other standards. The highly flexible motion model and the very efficient context-based arithmetic-coding scheme are the two primary factors that enable the superior rate-distortion performance of AVC.

Table 1 Comparison of Average Bit Rate Savings among Codecs

Coder	MPEG-4 ASP	H.263 HLP	MPEG-2
H.264 AVC	38.6%	48.8%	64.5%
MPEG-4 ASP	-	16.7%	43.0%
H.263 HLP	-	-	30.6%

Although not discussed in their article, the bit-rates for HD video at broadcast quality are reduced by a factor of between 2.25 and 2.5 when using AVC coding.

Conclusion
The article quoted above uses simple objective criteria to find that AVC bit rates can be less than half those needed by MPEG-2. Our own informal qualitative evaluations of typical HDTV material support the conclusion that AVC or WM9 at bit rates of 6-9 Mbps provide video quality not materially different from MPEG-2 at 18.6 Mbps (the nominal video bit rate of the 19.4 mbps ATSC signal).

Carrying All Markets and Stations at 19.4 Mbps
In this section the consequences of not using the techniques outlined in this Plan are examined. This Plan indicates that all full power local stations can be carried in HDTV format by a satellite system at one orbital location using the following resources and techniques:

- 720 MHz of Ka-band spectrum divided into 46 frequencies
- Collocation of two high power satellites
- Multiple spot beams that enable 8x frequency re-use
- Source coding in AVC or WM9 to reduce the average bit rate for HDTV to 7 Mbps
- 8-PSK modulation and rate 2/3 Turbo or LDPC channel coding to give 41 Mbps information rate per transponder
- Statistical multiplexing of an average of five HDTV signals per transponder
- Adaptation of conditional access system implementation to enable a common platform

None of the items in the list involves high risk and all of the technologies should be available in the time frame required to implement this Plan. The key question is whether HDTV at an average rate of 7 Mbps is not materially different from broadcast MPEG-2 HDTV. We argue that it is not. But what are the consequences of requiring DBS operators to carry all full power local stations at 19 Mbps?

Using conventional QPSK modulation and FEC, a transponder will transport 41 Mbps total. With rate ¾ FEC this yields an information rate of 30.75 Mbps, which is sufficient for only one 19 Mbps signal. Even at rate 7/8 the information rate of 35.875 Mbps is insufficient to carry two 19 Mbps HDTV signals. Under these conditions the satellite operators need five times as many satellites and Ka-band orbital slots as the system in this Plan. If they use DBS or FSS frequencies which are limited to 500 MHz per orbital slot, the situation is worse by a factor of 46/30. These calculations show why operators sometimes use less than 19 Mbps for MPEG-2 HDTV.

Assuming all the conditions in the above list pertain, except that the 7 Mbps AVC rate is replaced by MPEG-2 at 18.6 Mbps, then two MPEG-2 HDTV signals can be multiplexed in a transponder instead of five AVC signals. The operators therefore need 5/2-times as much capacity, which means five satellites in three orbits. Even if operators use 12 Mbps MPEG-2 to multiplex three signals into a transponder they need 5/3-times as much capacity or four satellites in two orbital slots. And if the operators use DBS or FSS frequencies instead of Ka-band, then the number of satellites rises by 46/30. Assuming the operators do not adopt a common platform to deliver local stations, each of them needs to provide this level of resource.

The Plan outlined here is a practical way to carry all stations in HDTV. It also affords the operators a significant level of savings by defining a common platform that delivers the signals to the subscribers of all DBS services.

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